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The evaluation of form deviations during teeth manufacturing of gear rings

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Abstract

The aim of research is to perform the analysis of geometrical form of internal and external teeth of gear rings where external teeth are involute splines. These gear rings are applied in aircraft engineering in planetary gear trains. The authors present a general manufacturing process of gear rings and the measurement results of form deviations. The analysis of manufacturing errors of gear rings is presented - starting with first manufacturing operations and ending with the final product. The influence of these errors on design features of the manufactured product is also shown.

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Keywords: gear rings, form deviations, planetary gear

1. Introduction

Gear rings are applied in mechanical engineering in many technical solutions, among other things in planetary gears used in aircraft engineering. The quality requirements for gear rings applied in planetary gears force process engineers to use gear and machine tools with equivalent quality and to apply new materials.

Final manufacturing accuracy of the geometrical form of a gear ring depends on many technical factors. The designers should pay a special attention to datum surfaces and should take into account the influence of thermochemical treatment on the successive manufacturing operations. Form deviations with different types of profile such as oval or three-lobe profile play an essential role.

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Form deviations are usually present due to the application of a bad or improper mounting of a workpiece. During machining and as well as thermochemical treatment the gear rings are being deformed. Form deviations have an effect on tooth profile error, cumulative pitch error and radial run-out of the pitch diameter of a gear ring.

If the manufacturing process is incorrectly elaborated, then the application of modern stock of machine tools and high quality gear tools does not guarantee to obtain the assumed shape of gear teeth.

2. The aim and methodology of research

2.1. Design features

The aim of research is a gear ring with an involute tooth profile which has internal and external teeth. External teeth are involute splines and are applied to mount directly the gear wheel on the shaft. A single part drawing of the gear ring is presented in Figure 1. The gear ring is made of carburizing alloy steel AMS 6265 with the following chemical composition: C–0.08÷0.13%, Si–0.15÷0.35%, Mn–0.45÷0.65%, Cr–1.00÷1.40%, Mo–0.08÷0.15%, Ni3.00÷3.50%, P–0.025% max, S–0.025% max.

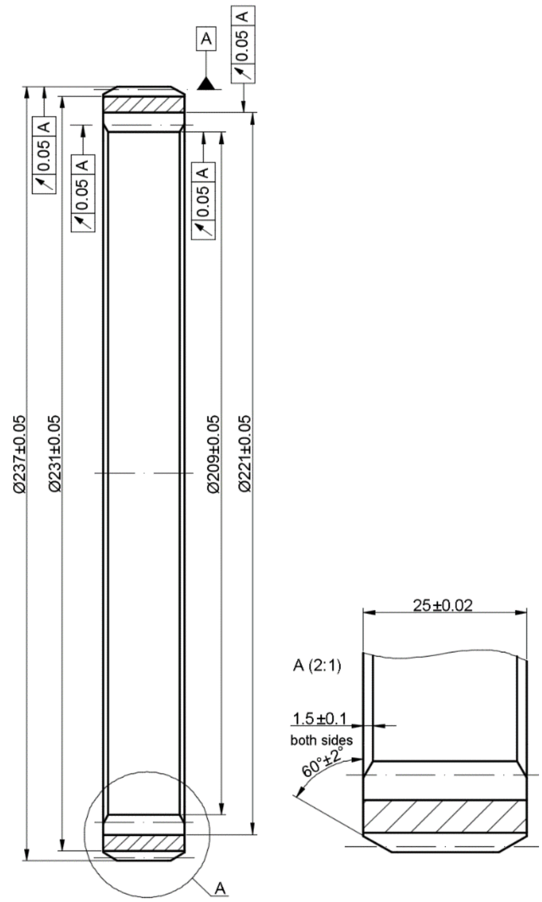

Table 1. Internal teeth parameters

Number of teeth	z = 84
Module	m = 2
Pressure angle	$\alpha = 20^{o}$
Tip clearance	c = 0.65
Pitch diameter	$d_p = 213.4$
Base diameter	$d_z = 193.5$
Dedendum diameter	$d_w = 221.5$
Fillet radius	R = 0.5 min
Tooth thickness	g = 3.4 ±0.025
Accuracy class	6 - c

Table 2. Involute spline parameters

Number of teeth	z = 111
Module	m = 2
Pressure angle	$\alpha = 30^{o}$
Pitch diameter	$d_p = 235.2$
Base diameter	$d_z = 220.9$
Dedendum diameter	$d_w = 231.4$
Fillet radius	R = 0.85 min
Tooth thickness	g = 3.31
Accuracy class	6

Fig. 1. Production drawing of a gear ring

The gear ring (Fig. 1) is very susceptible to deformations for large diameters due to the thin wall between the internal and external teeth [4].

Gear ring deformations with the shape of roundness deviations (e.g. oval, 3-lobe) are the reason of occurrence of dimensional deviations and incompatibility of the teeth shape with the constructional assumptions and standards of manufacturing accuracy of teeth [5, 6]. These deformations have an influence on the tooth thickness measurements and run-out of the pitch diameter of internal teeth in relation to the pitch diameter of involute spline. Due to these deformations gear rings are subjected to additional correction machining and are often declared as rejected parts.

Gear rings are subjected to thermochemical treatment because of their performed function in planetary gears. Internal teeth are carburized and hardened, and the structure of involute spline is only heat treated. The investigated gear ring was made of forging (quenched and tempered) or blank with the shape of a bar. The bar was cut as a blank and it was heat treated in order to get the hardness in the range 32÷35 HRC.

2.2. The research methodology of a gear ring

The investigations were done for one series of gear rings which consisted of ten specimens. The entire manufacturing process of the gear ring was analysed. This process consisted of 14 operations - starting with blank preparations, rough turning and ending with grinding. The following seven significant operations were chosen for the investigations: half-rough turning, shaping of internal teeth, thermochemical treatment, grinding of internal diameter, grinding of external diameter, grinding of internal teeth and grinding of involute spline. The aim of research was investigation of the mutual influence of the successive manufacturing operations and the values of form deviations due to these operations [1, 2, 3]. It was necessary to find the answer to the following questions: Do the manufacturing errors from one operation have an influence on the manufacturing errors of next operations? Are these errors accumulating? After every manufacturing operation, the measurement of roundness deviations was done with the application of the coordinate measuring machine for gears Klingelnberg P-40. This measurement was performed in order to check the value of deformation. The coordinate measuring machine was equipped with the software for the measurement of geometrical features and form deviations of spur and bevel gears and it was also equipped with the software "Shaft" for the measurement of form and position deviations. After the following operations: *shaping of internal teeth, thermochemical treatment, grinding of internal teeth and grinding of involute spline*, the run-out deviation of teeth was measured and registered.

3. The measurement results of form deviations

After the operation of *half-rough turning*, the measurement of roundness deviations of internal and external diameters of teeth was done. The values of the form deviations are presented in Figure 2. On the basis of the analysis of these values one can conclude that the highest values of the roundness deviation for the external diameter of teeth were generated after the turning operation of the internal diameter.

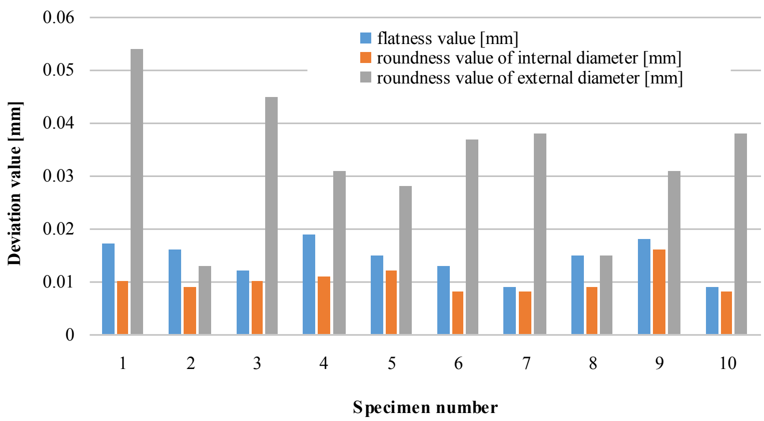

Fig. 2. The values of form deviations after the turning operation

Before the thermochemical treatment, the next operation of *shaping of internal teeth* was done with the application of the Fellows shaping machine. On the basis of the measurement results of the teeth run-out one can conclude that the run-out value has considerably exceeded the allowable value which is dedicated in the process documentation (maximally – two times).

Thermochemical treatment consisted of carburizing, hardening and low temperature tempering. The values of the form deviations obtained after this operation are presented in Figure 3, and the values of the teeth run-out are shown in Figure 4.

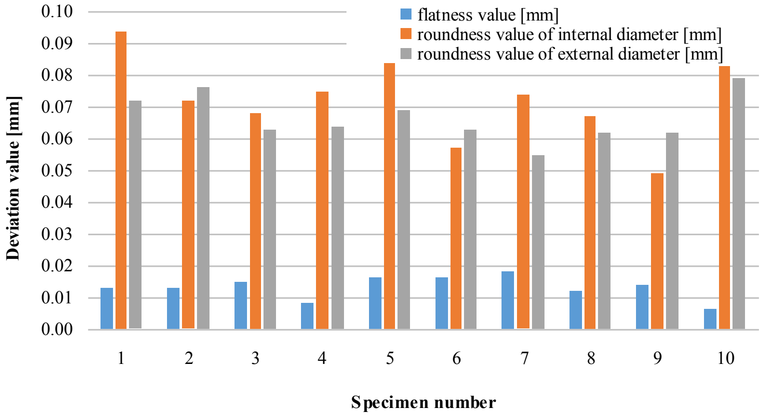

Fig. 3. The values of form deviations after the thermochemical treatment

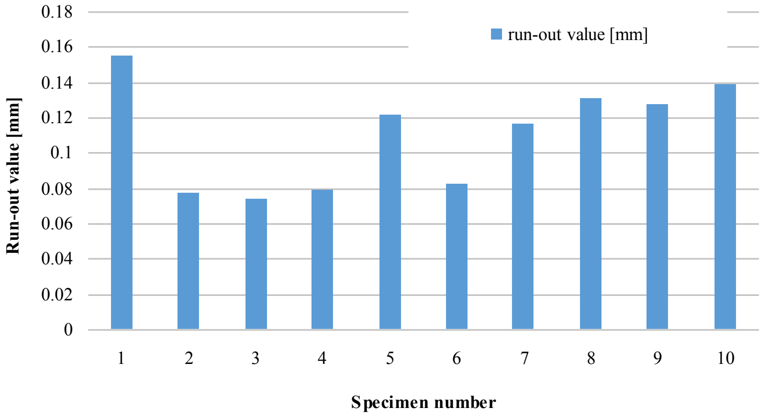

Fig. 4. The values of teeth run-out after the thermochemical treatment

Grinding operations of internal diameter and then external diameter (Fig. 1) were done as separated processes. The values of the form deviations are compared in Figure 5.

After the operations of *grinding of internal teeth* and *involute spline teeth*, the measurements of form deviations were done. The values of the form deviations for both operations are illustrated in Figure 6. The measurement results of the *run-out of internal and external teeth* are shown in Figure 7.

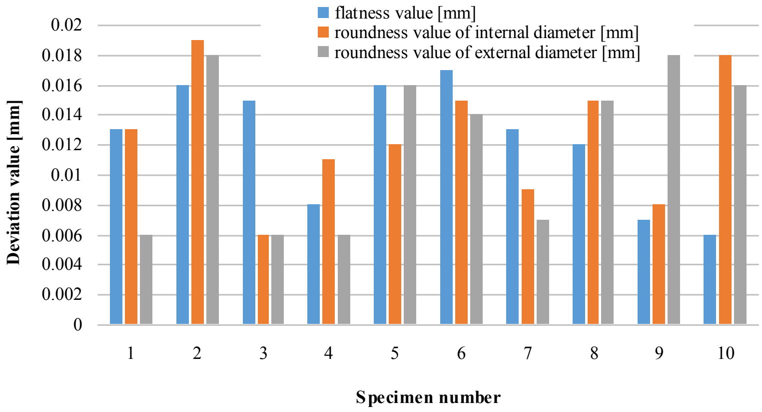

Fig. 5. The values of form deviations after grinding of internal and external diameter

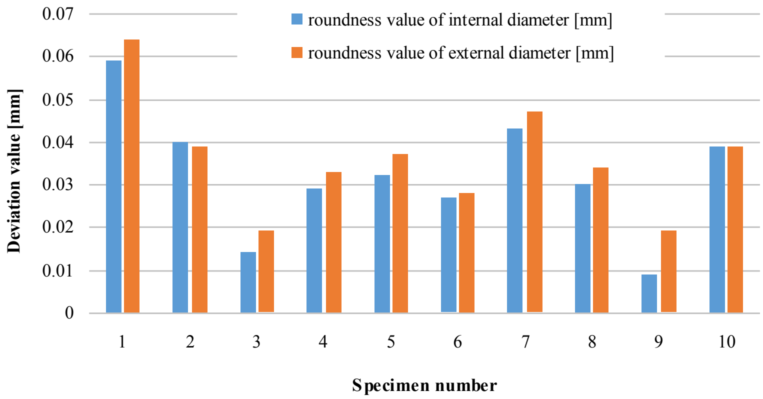

Fig. 6. The values of form deviations after grinding of internal teeth and involute spline teeth

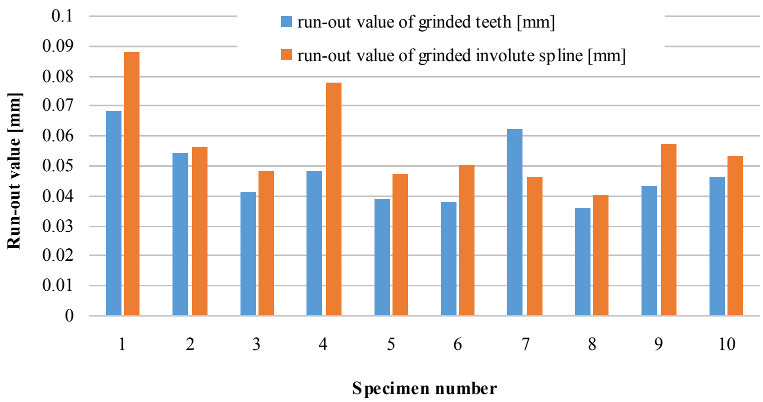

Fig. 7. The values of run-out of internal teeth and involute spline teeth

On the basis of the analysis of the form deviation values for different manufacturing operations one can conclude that the highest deformations with oval profile occur during the operation of *thermochemical treatment*. The values of these deviations are in the range 0.057 – 0.079 mm and are about 5 or 6 times higher in comparison with turning or grinding operations of the diameters of external and internal teeth. These values are about two times higher in comparison with grinding operation of external and internal teeth.

4. Final conclusions and summary

Summarizing the measurement results, we can conclude the following statements:

1. *Turning of the diameter* in a three-jaw chuck is the reason of occurrence of the oval profile with the mean value 0.010 mm for internal diameter and 0.033 mm for external diameter. The ovalization of the external diameter is the reason of transmission of datum deviation of internal diameter during alignment (centring).

2. During the *shaping* operation we can observe the increase of the run-out value of the teeth pitch diameter and its mean value is equal 0.061 mm. For this stage of manufacturing, the run-out value of the pitch diameter is exceeded about 0.011 mm in relation to the set value in project documentation.

3. During the operation of *thermochemical treatment* the mean value of oval is equal 0.072 mm for internal diameter and 0.067 mm for external diameter. The value of the run-out deviation of the pitch diameter is averagly equal 0.11 mm and it has increased about 0.051 mm in relation to the state after the shaping.

4. During the *shaping operations of internal and external diameters* the values of form deviations are significantly decreased. Internal and external addendum diameters are subjected to grinding. So, the deformation was decreased to the value 0.013 mm for internal diameter and 0.012 mm for external diameter.

5. The *grinding operations of internal teeth and involute spline teeth* have an impact on the final shape of a gear ring. The product quality depends on these operations. During grinding of internal teeth and involute spline teeth the shape deformations are occuring again with the value about 0.025 mm, and the run-out value of the pitch diameter is in the range 0.036 ÷0.068 mm for internal teeth and 0.040 ÷ 0.088 mm for involute spline teeth - these values have exceeded the set value 0.050 mm. A special role in manufacturing plays the run-out deviation of the pitch diameter of internal teeth which is a datum feature during the grinding of involute spline teeth. The deformation of the pitch diameter of internal teeth has an influence on the run-out of the pitch diameter of invoute spline.

On the basis of the measurement investigations during the manufacturing of a gear ring we can come to the following conclusion: to ensure the required quality of the final product, one should minimize form deviations of the datum surface during the process designing of gear rings. Form deviations have an impact on the successive manufacturing operations. These errors transfer not only their form and dimensional deviations, but also make some difficulties to machine operators, inspectors and process engineers during their proper interpretation. It is necessary to analyse permanently the results of dimensional and form deviations particularly during the unstable manufacturing process of gear rings and it is necessary to apply quality tools such as SPC control charts.

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